DOE/NASA TECHNICAL MEMORANDUM

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DEVELOPMENT, TESTING AND CERTIFICATION OF THE SIGMA RESEARCH, MAXI-THERM S-101 THERMOSYPHON HEAT EXCHANGER -- FINAL REPORT

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Solar Energy

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PROGRAM BACKGROUND AND GOALS

Before dealing with the specific aspects of the Sigma Research exchanger, a few background statements are pertinent. The problems of energy availability and increasing costs have led to a major national effort to develop alternate energy sources. One such source is the energy in solar radiation which can be used for heating and cooling buildings, domestic hot water, and other applications. The National Energy Policy, as established in the Solar Heating and Cooling Demonstration Act of 1974 (PL93-409), provided for the demonstration within a 3-year period of the practical use of solar heating technology, and demonstration within a 5-year period of the practical use of combined heating and cooling technology. Responsibility for implementing the Demonstration Act was given to the Energy Research and Development Administration (now the Department of Energy). The National Aeronautics and Space Administration (NASA), George C. Marshall Space Flight Center (MSFC) manages a large part of this work.

PRODUCT DEVELOPMENT CONTRACT

The purpose of this contract was to provide Sigma Research with funds to do additional development, design and testing on their existing passive Thermosyphon solar heating module (with supplementary heating) to make a marketable product and for the procurement of the developed subsystem. Each subsystem consists of one heating module (passive heat exchanger) and one submersible electric water heating element.

During the product development effort, the contractor was required to:

1) Meet the pertinent parts of the Interim Performance Criteria.

2) Meet the Subsystem Performance Specification

3) Conduct tests and provide test data/analysis to verify that hardware meets the Subsystem Performance Specification

4) Provide drawings and specifications in sufficient detail to define the configuration and to ensure manufacturing repeatability

5) Provide installation, operation and maintenance manuals(s)

6) Provide subsystem and/or component hardware certification by an independent test laboratory (such as, Underwriters Laboratory and American Gas Association) to meet nationally recognized standards and codes (such as, American Society of Heating, Refrigeration and Air Conditioning Engineers; American Society of Mechanical Engineers; American National Standards Institute and American Refrigeration Institute).

DESCRIPTION

The Maxi-Therm S-101 is a thermosyphon heating module utilizing a horizontal liquid-to-air heat exchanger, a Dayton direct drive blower and an automatic air shut-off damper. Figure 1 shows a view of the damper (air shut-off valve) and the heat exchanger while Figure 2 shows the complete module with heat exchanger removed.

Heat Exchanger

The performance of the Maxi-Therm is determined primarily by the effective performance of the liquid to air heat exchange element. For this reason, a great portion of the activity was spent on the further development of the design of this element.

During the phases of development, the exchanger module was reoriented to a horizontal rather than a vertical position. The rationale for the vertical to horizontal switch was better performance. For vertical thermosyphons operating in the heating mode (Fig. 3), water enters at the top, flows vertically downward through the heat transfer elements, and exits at the bottom of the exchanger prior to reentry into the thermal storage tank. During its downward movement, the water gives up heat to the air, thus falling in temperature and rising in density. The pressure which drives the water flow in the system then originates due to the density differential existing between the water in the heat transfer elements of the exchanger and the storage tank.

In a horizontal thermosyphon (Fig. 4), a somewhat different driving pressure expression is realized since the rise in density of the water occurs during flow in a horizontal plane. Before entering the vertically oriented outlet piping, which connects the exchanger outlet to the bottom of the tank, the water has already reached its maximum density. The horizontal possesses a greater driving pressure differential and, consequently, a higher mass flow rate is realized.

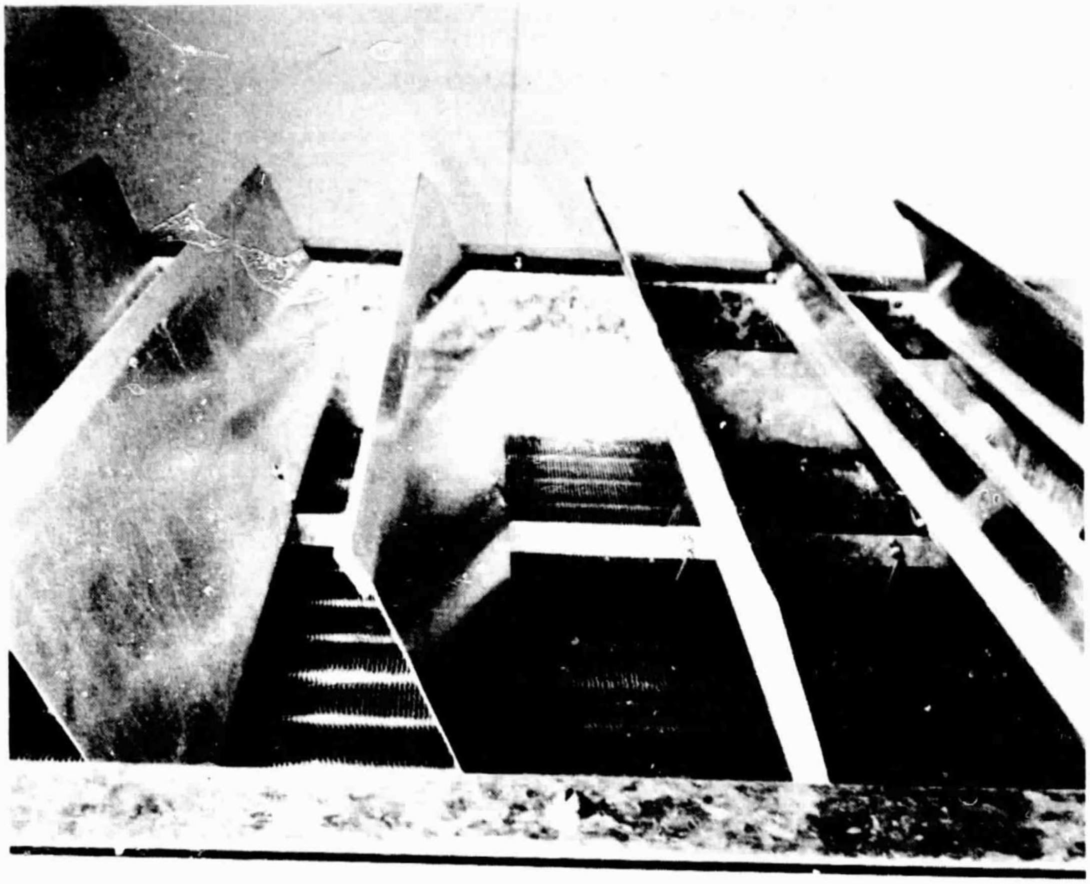


Figure 1. Top view of damper and heat exchanger.

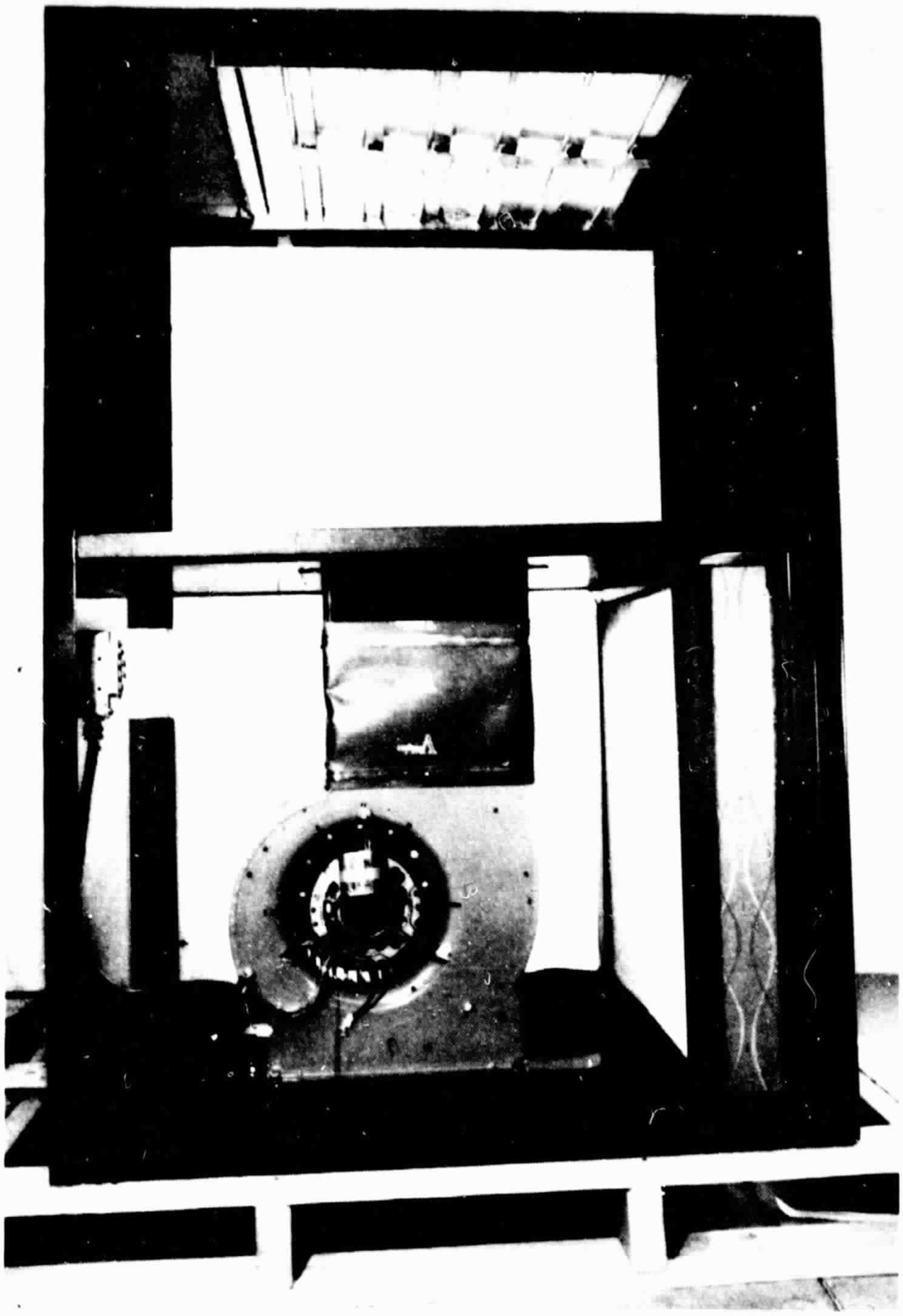


Figure 2. Interior view with heat exchanger removed.

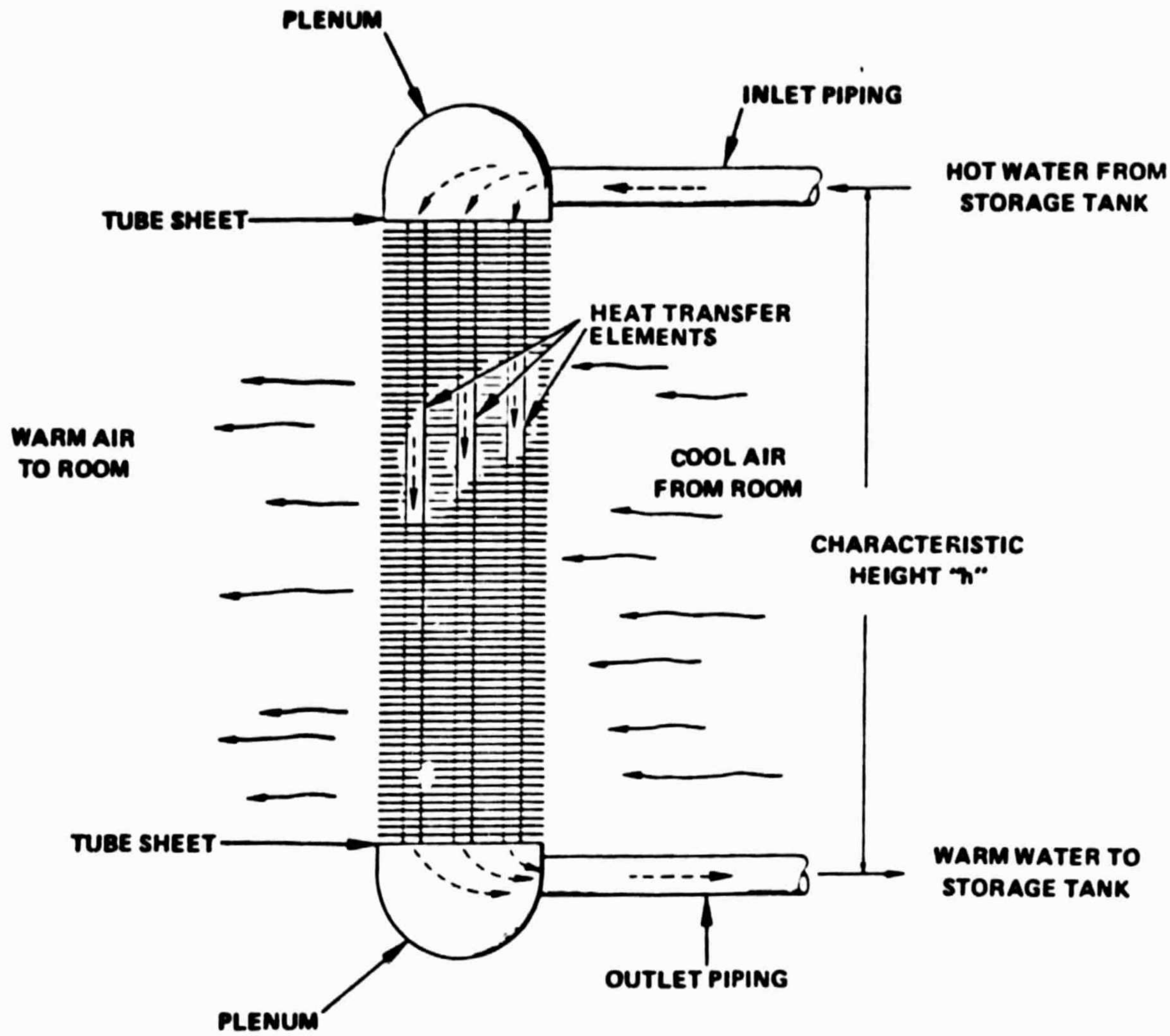


Figure 3. Basic design of a vertical thermosyphon heat exchanger for use with liquid thermal storage tanks.

Another reason for the position change was the additional advantage provided by the horizontal exchanger position in relation to the circuiting of liquid flow in the heat transfer elements. The vertical unit is constrained to use only multiple parallel paths connected to common plenums at each end. The horizontal unit may utilize totally parallel or parallel-series circuiting. In Figure 5 a comparison is shown between the flow in a total parallel system and in one type of parallel-series arrangement.

In the change-over from vertical to horizontal, special attention had to be paid to the inlet and outlet piping. The reason for the special

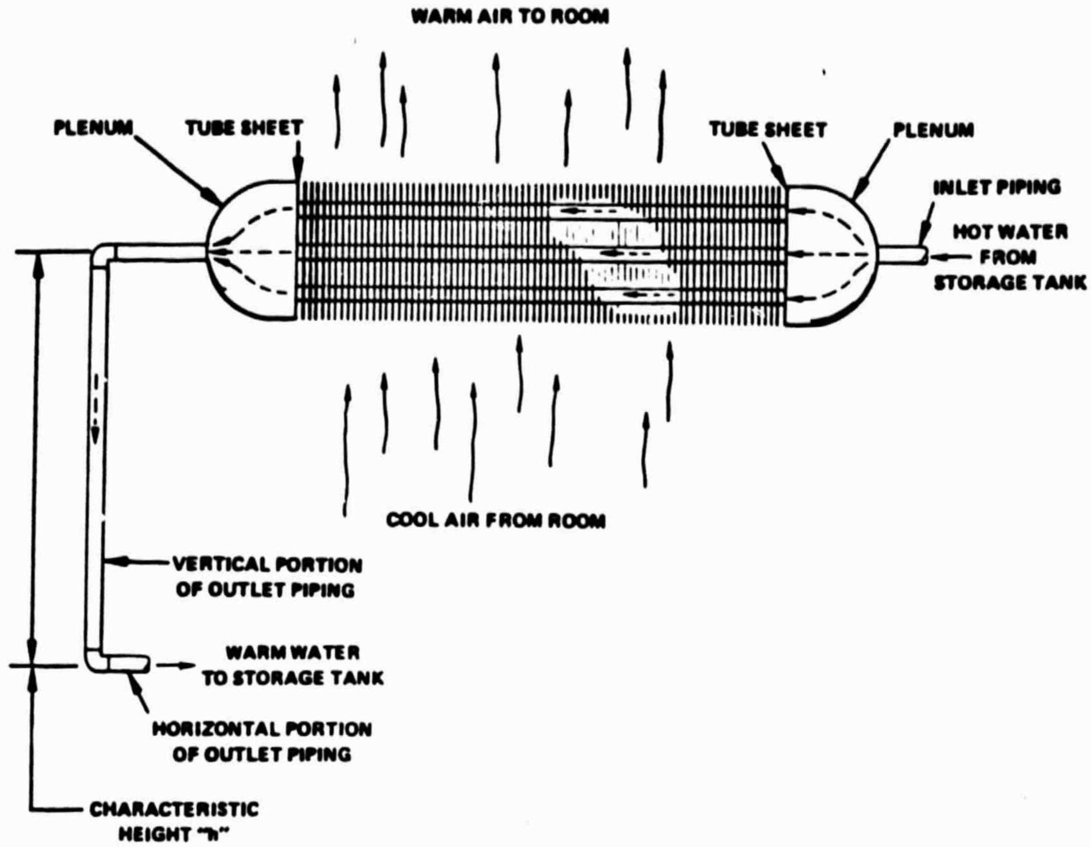
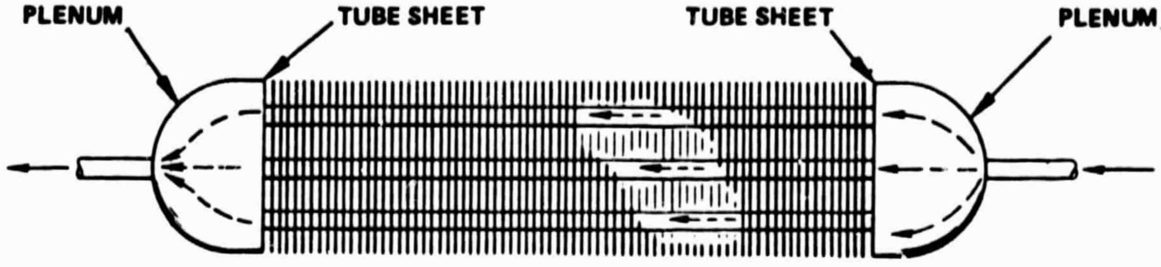


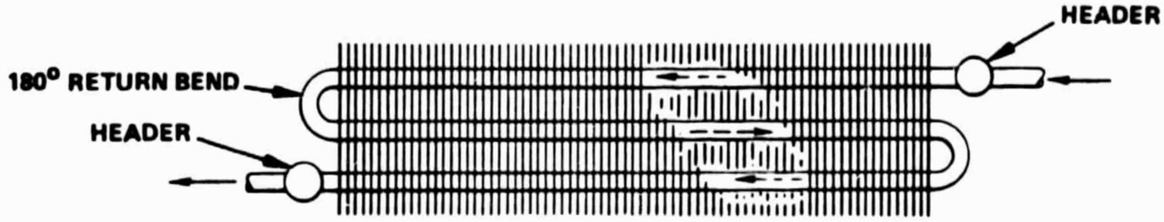
Figure 4. Basic design of a horizontal thermosyphon heat exchanger for use with liquid thermal storage tanks.

attention was that the primary heat transfer elements in the horizontal position do not form the vertical link necessary between tank exit and inlet.

In order to minimize pressure drop in piping and thus increase the mass flow rate, it was advantageous to increase pipe diameter and decrease pipe length. However, it was further determined that a decrease in outlet pipe length, in the case of the vertical portion, is not desirable since it is this length that determines the thermosyphon driving pressure. It was also determined that a decrease in the horizontal position is likewise undesirable, since sufficient distance must be provided between the Maxi-Therm unit and the storage tank to permit the installation of pipe couplings. Therefore, it was determined that the diameter change is the best variable to use if a lower system pressure drop is required. A change in this variable also produces the most effect on piping pressure loss.



HORIZONTAL THERMOSYPHON WITH PARALLEL FLOW CIRCUITS



HORIZONTAL THERMOSYPHON WITH PARALLEL-SERIES FLOW CIRCUITS

Figure 5. Horizontal thermosyphon with parallel flow circuits and horizontal thermosyphon with parallel-series flow circuits.

The final design of the heat exchanger module was completed in March of 1977. The final element is a 56-tube, parallel-series flow arrangement with four tubes in a series. This module is commercially available from suppliers.

Cabinet

The primary purpose of the cabinetry for the Maxi-Therm is to provide maximum satisfaction to the potential market. The Maxi-Therm cabinet was designed to provide a pleasing appearance, easy module maintenance, low cost production, and simple assembly and disassembly.

In Figure 6, a conceptual view is shown of the Maxi-Therm S-101 module with the exterior shell in place. As noted in Figure 6, the shell consist of basically four sections, labeled A, B, C, and D. By designing the shell in this manner, a number of advantageous features were made possible.

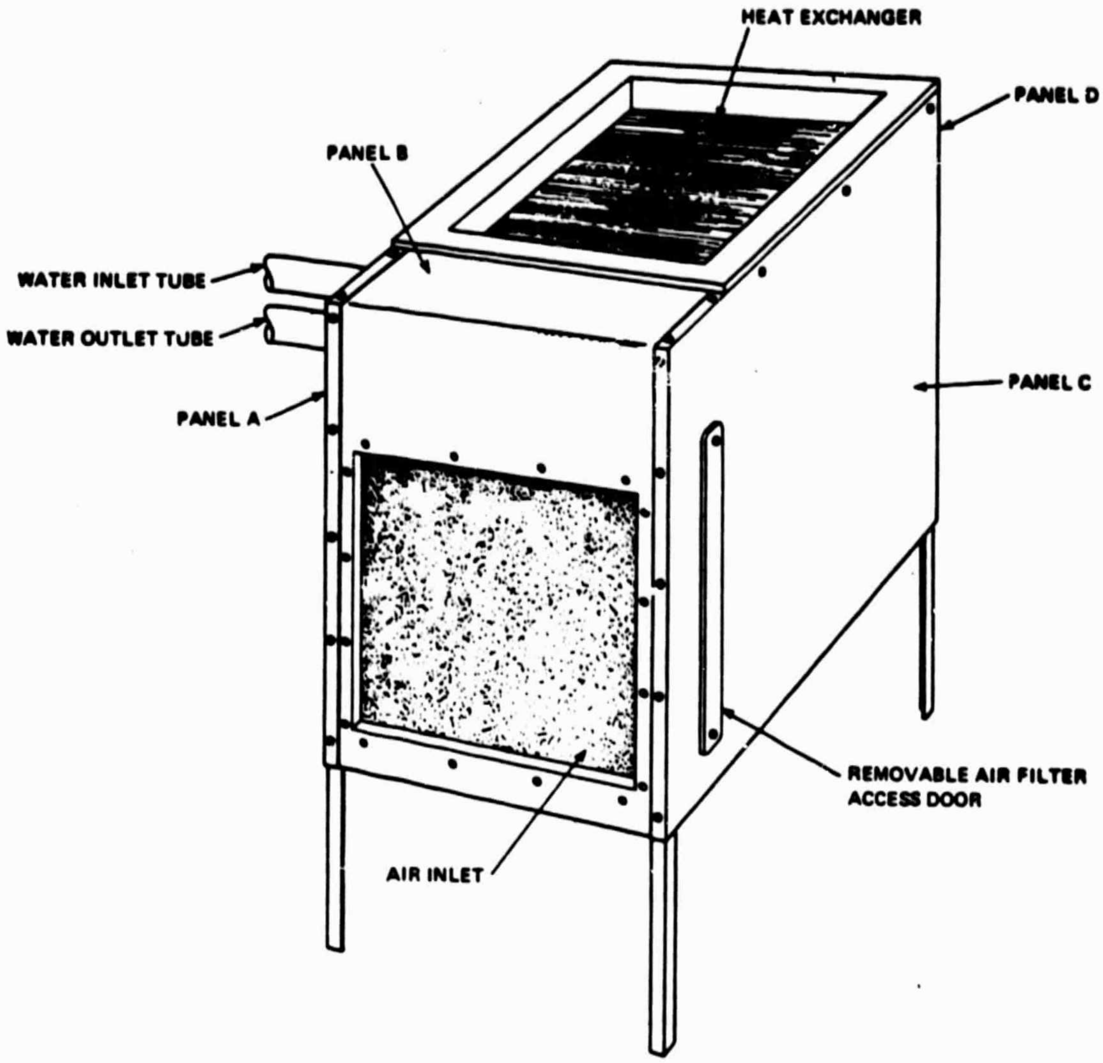


Figure 6. Conceptual view of prototype Maxi-Therm S-101 with cabinet installed.

First, in the production of the shell, the formation of complicated or intricate bends is not required, thus permitting the components to be manufactured on a normal brake and shear. In addition, the use of Panels A and C to form the finished corners permits Panels B and D to have flat, as-produced edges and further decreases the number of critical dimensions required in their production.

Combining the function of the cabinet with other requirements is also possible with this design. As shown in Figure 6, a portion of Panel B acts as the air inlet and the filter holder is attached to its backside.

Access to this filter is provided by the indicated removable cover on Panel C. The cabinet as a whole further acts as both the inlet and outlet air plenums, with a horizontal sheet steel divider separating the two sections. The seal between the inlet and outlet plenum is provided by foam rubber strips which are bonded to horizontal frame stiffeners positioned directly below the divider and extending the entire circumference of the unit.

Originally, the entire electrical component package was considered for mounting within the shell. This design, however, was modified to position the electrical components within a separate electrical box attached to the outside of Panel D. Primarily, this was done to eliminate possible conflicts with local electrical codes concerning the danger of 115 Vac junctions in the proximity of a heat exchanger containing water.

Shut-Off Valve

During the early development of a thermosyphon water-to-air heat exchanger, it became apparent that the unit possessed one particular trait not usually found in heat exchangers, that being the requirement for a positive shut-off valve. In normal forced flow exchangers, cessation of water pump operation is sufficient to halt exchanger operation. In thermosyphon units, however, the movement of air through the exchanger and the subsequent decrease in water temperature create the liquid driving force which increases the liquid circulation. To shut the device off, either air movement of liquid circulation must be eliminated.

Initially, investigations were made into the use of a water-side shut-off. This type of device, it was found, would require use of an electric solenoid, a component which added both cost and a potential area for maintenance/repair in the future. In addition, most types considered required a movable shaft and sealed penetration through some portion of the transfer system piping. Besides the cost, this represented a potential area for leakage and additional maintenance. Another consideration was the possible effect on transfer system pressure drop that a valve, even in the full open position, would create and the corresponding effect that it would have on module thermal performance.

When it was found that a water-side shut-off would not be desirable, investigations were commenced to define possible air-side shut-off valves. Since the position of the valve with respect to the heat exchanger has a strong bearing on the design, this was the first area to be investigated. Consideration was given to two locations during these studies, one being the outlet ducting and the other, the plenum area immediately above the heat exchanger. Since the outlet ducting will not be included with the Maxi-Therm unit, the installation of a factory supplied shut-off in the outlet ducting would entail additional cost to the

homeowner and would not guarantee proper installation. In addition, insulation would be required on the section of ducting between the exchanger and shut-off valve to avoid excessive heat loss. These drawbacks were felt to be serious enough to consider the second location, which is within the outlet plenum. Although this position does require fitting the valve to a predetermined opening size, thus eliminating flexibility in sizing, it does eliminate the need for additional insulation and allows the valve to be installed at the factory.

Following selection of the latter position for the valve location, attention was next turned to the design of the component. For this application, a multi-vane damper similar to that shown in Figure 7 appeared to be a good choice, with the method of actuation being the only area of investigation. Basically, this actuation can be provided by either a motor or differential pressure across the damper, such as that generated by the blower fan. The latter of these two was the preferred choice, since the cost of a motor and the associated linkage generally raises the price by \$50-\$100. In addition, the passive opening system does not require maintenance or adjustment after leaving the factory.

The multi-vane damper was selected in March of 1977. The item was procured from a supplier and is commercially available.

PERFORMANCE

The Maxi-Therm S-101 will deliver more and more heat as the inlet water temperature increases. The air handling fan is rated at 1640 cfm, and is operated by a 1/3 hp, 6.5 amp full load, 115 Vac motor. This air flow is delivered at 0.6 in. water static pressure to provide adequate air distribution throughout the home. The performance of the Maxi-Therm S-101 heating performance is depicted in Figures 8 and 9.

CONCLUSIONS AND RECOMMENDATIONS

This contract was successfully completed during October 1977 with the acceptance, by Marshall Space Flight Center, of three subsystems which had been inspected, tested and verified to exceed the expected design performance criteria.

No major problems were encountered during the development of the subsystems, although the heat exchanger position was changed from vertical to horizontal, and the exchanger tube size, due to economic factors, was limited to the commercially available maximum.

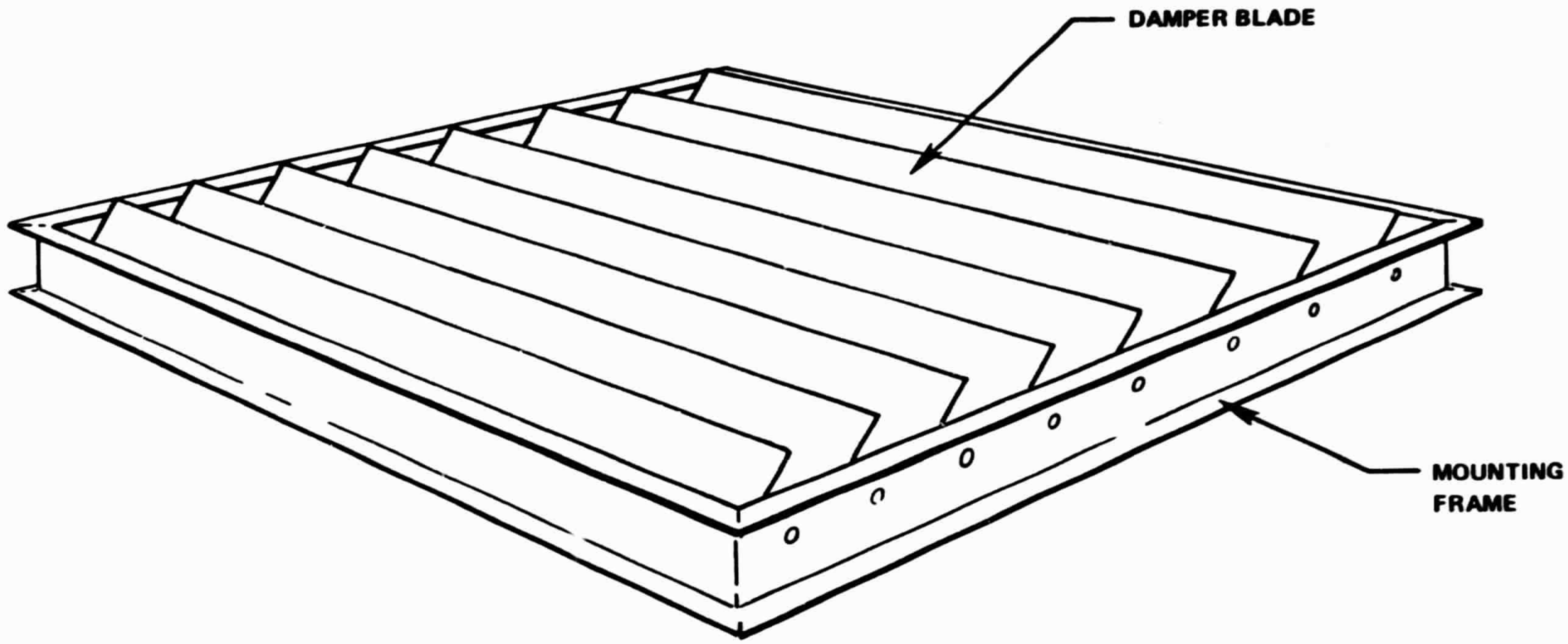


Figure 7. Passive control air shut-off damper for horizontal thermosyphon heat exchangers.

Inlet Air Temperature	Tank Mean Water Temperature	Heat Output
70°F	100°F	18,000 BTU/Hr
	110	26,000
	120	35,000
	140	54,000
	160	74,000

Figure 8. Maxi-Therm S-101 heating performance.

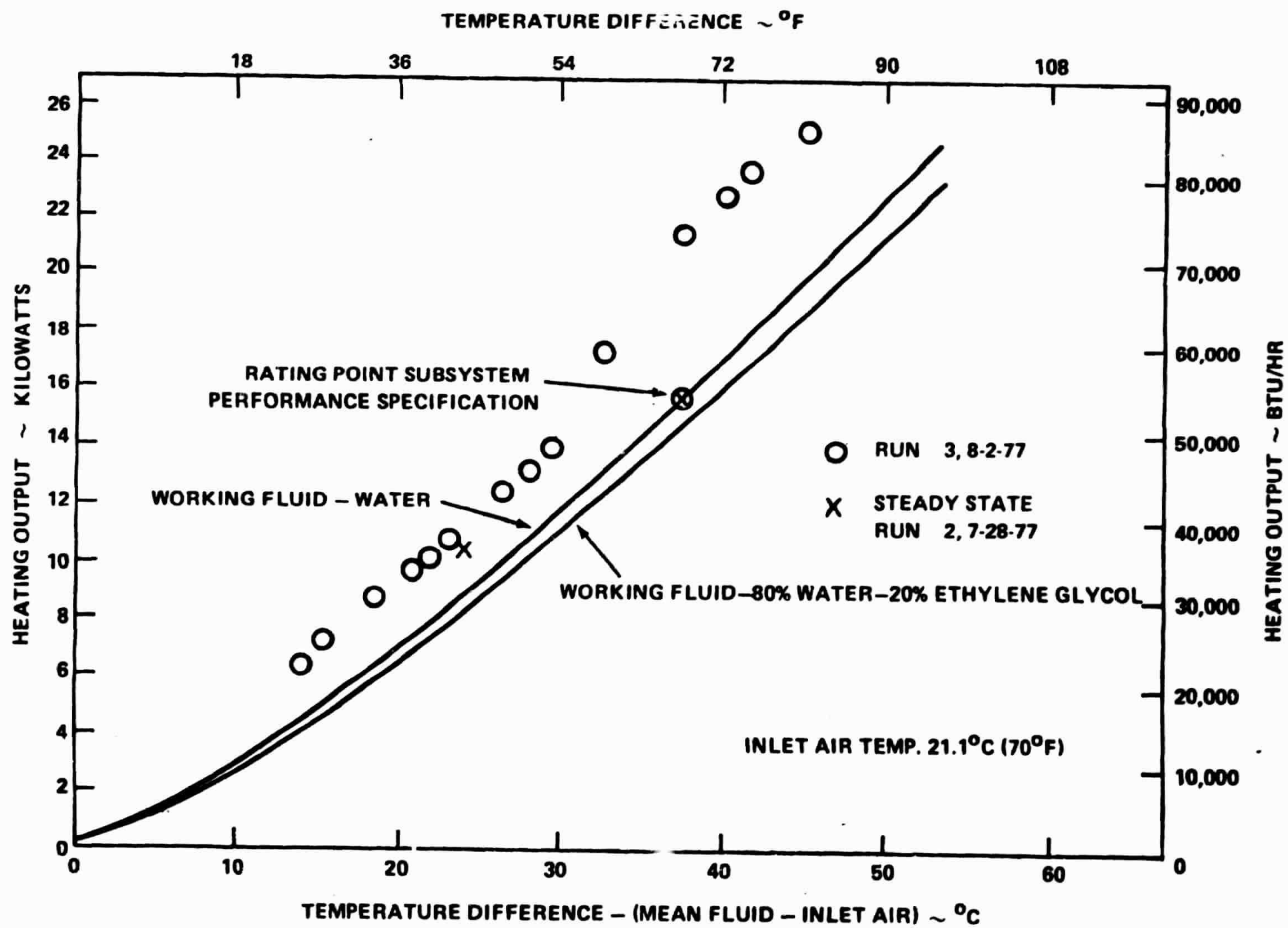


Figure 9. Minimum performance characteristics of Maxi-Therm model S-101.

The technology for thermosyphon systems is not new. Many of the early (and late) solar hot water systems use thermosyphon circulation technologies. The origin of the term "thermosyphon" is uncertain, but the name did appear as early as 1928 in the sales literature of Deere (John) and Company cooling systems. The Model T Ford is perhaps the first automobile to use thermosyphon cooling.

Passive thermosyphon systems are inherently less expensive to operate and maintain than active systems. In the past, many thermosyphon solar hot water heating systems were used because electricity or other conventional energy was not available or too expensive. That same situation is rapidly approaching again — but on a much larger scale. Because thermosyphon devices can be designed, and are available, to conserve energy without imparing performance, they should be considered for use in many solar heating systems.

The Maxi-Therm S-101 developed during this contract is not yet available as an off-the-shelf item. Production, other than special orders, will be determined by market potential and demand. Sigma Research, Inc., Richland, Washington, should be contacted for additional information.

REFERENCES

1. Passive Thermosyphon Solar Heating and Cooling Module with Supplementary Heating (Quarterly Report) DOE/NASA CR 150849, Contract NAS8-32260, Sigma Research, Incorporated, Richland, Washington.

2. Installation Package Maxi-Therm S-101 Heating Module, DOE/NASA CR 150512, Contract NAS8-32260, Sigma Research, Incorporated, Richland, Washington.

3. System Design Package Maxi-Therm S-101 Heating Module, Passive Heat Exchanger, DOE/NASA CR 150516, Contract NAS8-32260, Sigma Research, Incorporated, Richland, Washington.

4. A Passive Thermosyphon Heat Exchanger for Residential Solar Applications, pages 27-30, Section 9, Volume one, Proceedings of the 1977 Annual Meeting, Orlando, FL, June 6-10, 1977, American Section/International Solar Energy Society, Killien, Texas.

Items 1 through 3 may be obtained through the Department of Energy, Technical Information Center, Post Office Box 62, Oak Ridge, Tennessee 37830, or Marshall Space Flight Center, Alabama. Item 4 may be obtained from American Section/International Solar Energy Society, Killien, Texas.

APPROVAL

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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